Physical and Optical Structures in the Upper Ocean of the East (Japan) Sea

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http://sahale.apl.washington.edu/jes/

LONG-TERM GOALS

This study fits within our broader scientific efforts to understand:

- Physical and biological responses of the upper ocean to atmospheric forcing and how these penetrate to the interior.
- The dynamics and biological influences of instabilities, secondary circulations and vertical motions associated with upper ocean fronts.
- Physical and bio-optical transitions between coastal and central basin waters.

OBJECTIVES

We seek to understand the processes that control physical and bio-optical variability in the upper ocean of the East/Japan Sea. Specifically, we are interested in:

- The upper ocean response to strong wintertime forcing (Siberian cold air outbreaks) at the subpolar front.
- The resulting formation, subduction, and spreading of intermediate waters.
- The dynamics of the subpolar front.
- Contrasting seasonal and coastal/central basin bio-optical variability.

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APPROACH

Two cruises, the first in May 1999 followed by a second in January 2000, sampled upper ocean and atmospheric boundary layer (Drs. C. Dorman, SIO, R. Beardsley and J. Edson, WHOI) variability in the Japan/East Sea. The spring cruise focused on frontal dynamics, characterizing bio-optical variability associated with the spring phytoplankton bloom and documenting the location, range and properties of water masses formed at the subpolar front during the preceding winter. The wintertime cruise documented the upper ocean response to a series of cold air outbreaks with particular attention to processes associated with water mass formation and subduction at the subpolar front. Both cruises employed a towed, undulating profiler (SeaSoar) to make highly-resolved observations of the upper ocean. We used real-time remotely sensed sea surface temperature and ocean color images (R. Arnone and R. Gould, NRL) to determine the location of the subpolar front and to select intensive survey locations. Real-time access to remotely sensed imagery allowed us to modify our sampling in response to changes in the front. Repeated intensive grid surveys provided approximately synoptic, three-dimensional coverage while a sequence of longer sections documented oceanic and atmospheric boundary layer variability away from the front. In addition to the suite of physical and bio-optical sensors carried by SeaSoar, we employed a shipboard Acoustic Doppler Current Profiler (ADCP) and GPS navigation to measure upper ocean currents. Sampling included a limited number of hydrographic stations and optical profiles off the Korean coast and across the subpolar front. Professor S. Yang (Kwangju University) was responsible for additional biological and bio-optical sampling (e.g. nutrient analysis, pigments). Dr. M. Suk (KORDI) and colleagues provided additional support.

WORK COMPLETED

Reports available at the web site listed above document the operational and data processing aspects of both spring and winter cruises. Both efforts involved scientists from the United States, Korea and Russia and included specialists in physical oceanography, biological oceanography, bio-optics, boundary layer meteorology and remote sensing. Motivated by the presence of a clearly defined, strong front, both spring and summer cruises sampled nearly identical regions situated over the northern side of the Yamoto Rise. SeaSoar sampling included intensive, quasi-synoptic surveys spanning a region roughly 100 km by 100 km. During winter, several sections extended farther north to encompass a warm eddy sitting just north of the subpolar front and to investigate marine atmospheric boundary layer structure as a function of distance from the source of the Siberian cold air outbreaks. Shipboard sensors made continuous measurements of meteorological variability while atmospheric soundings were carried out each day to obtain vertical profiles of temperature, humidity, pressure and winds. Underway measurements of absorption, scattering, attenuation and remote sensing reflectance were also collected (Dr. R. Arnone NRL).

Physical (Lee and Brink) and bio-optical measurements (Jones), including the shipboard ADCP (Lee and Brink) and meteorological (Beardsley and Dorman) data, have been fully processed and are being employed for scientific analysis. Initial efforts investigated intra-thermocline eddies found south of the subpolar front and employed SeaSoar observations to assist with an evaluation of the Navy's MODAS operational climatology and nowcast/forecast system. Papers detailing both of these efforts have passed review and are now in press. The collaborative intra-thermocline eddy study characterizes ubiquitous, large pycnostads found in selected locations south of the subpolar front and presents evidence suggesting that subduction at steep meanders may be responsible for their generation [*Gordon et al.*, 2001]. Evaluations of Japan/East Sea MODAS performance using remote sensing and SeaSoar measurements revealed weaknesses in the model's ability to extrapolate accurate vertical structure from surface measurements and illustrated potential pitfalls resulting from mismatches between observed short temporal/spatial scales relative to the longer scales measured by remote sensing [*Fox et al.*, 2001]. Collaborations have also been established between the SeaSoar investigators and ONR-funded Japan/East Sea numerical modelers (e.g. Moores, Hogan and Preller). These efforts focus on employing SeaSoar measurements in model evaluations and on using the numerical simulations to test our observationally-based results.

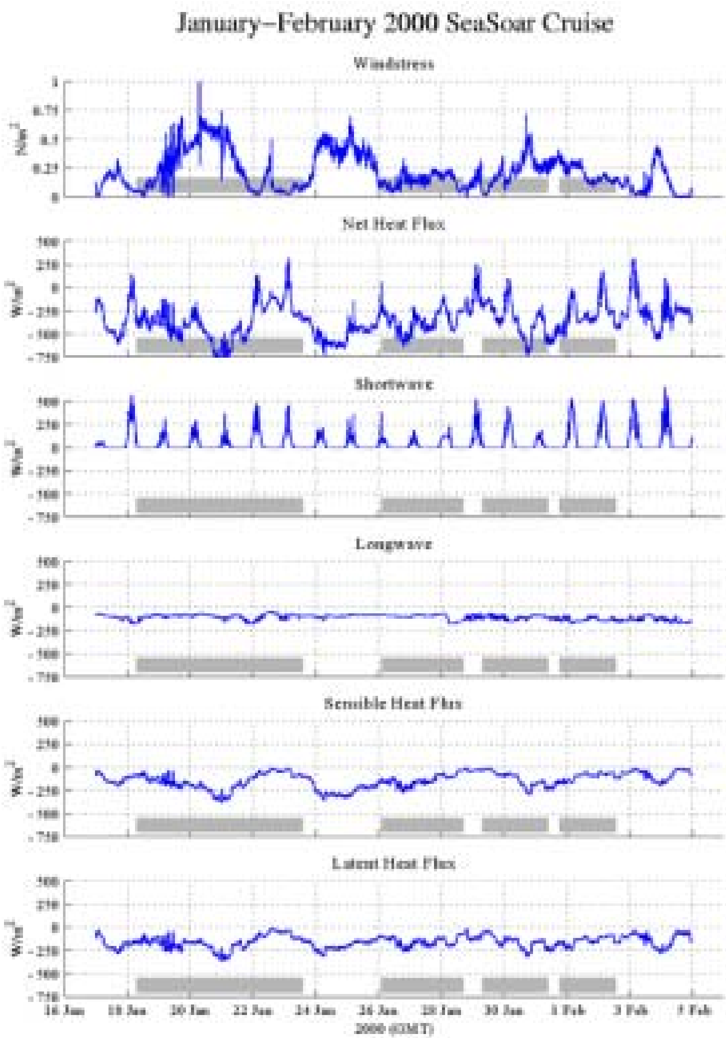
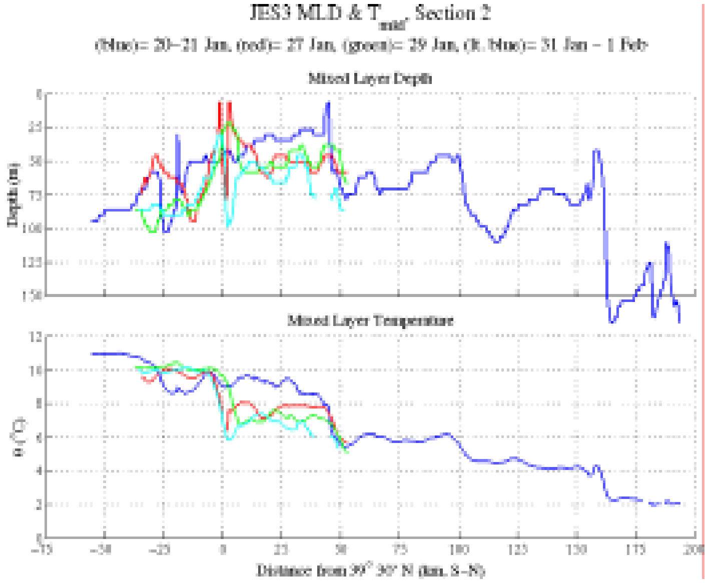


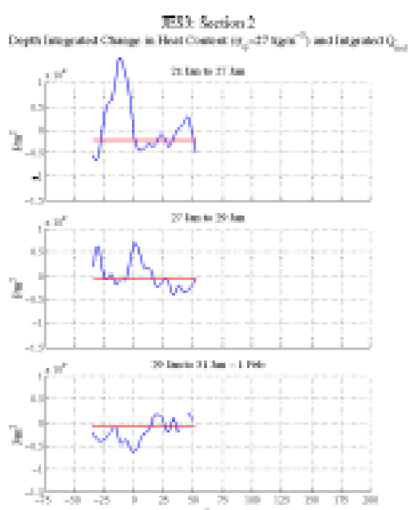
Figure 1. Heat flux components during the January 2000 cruise. Gray bars at the bottom of each panel mark the four occupations of the intensive survey grid. Latent and sensible heat fluxes govern variability in the net surface heat flux, producing strong losses during cold air events. Decreased shortwave flux during cold air outbreaks suggests cloudy skies during events followed by short, clear periods between outbreaks. Three distinct cold air outbreaks occurred during the sampling period. Events occurring around 21, 25 and 31 January lasted from 2-4 days and included strong winds from the northwest, air temperatures well below 0 °C and strong net surface heat loss.

RESULTS

Strong wintertime forcing by outbreaks of cold, dry Siberian air may drive intermediate water formation and subduction at the subpolar front of the Japan/East Sea. The subpolar front separates warm, saline southern waters from seasonally stratified, colder, fresher waters that lie to the north. Observations taken south of the front during spring and summer reveal subsurface pycnostads having elevated levels of dissolved oxygen and watermass characteristics consistent with those expected of waters formed in wintertime at the front. In January 2000, four repeat surveys sampled subpolar front evolution through three cold air outbreaks (Figure 1), including a particularly strong event that occurred 24-26 January, between the first and second surveys. Mixed layers deepened and cooled with the passage of each successive storm system (Figure 2), consistent with a largely one-dimensional response in which intense surface cooling and convective overturning play important roles. Between cold-air outbreaks, advective effects associated with both the front and a nearby eddy likely govern mixed layer evolution (Figure 2). Observations south of the front revealed small (O(20 km) horizontal and O(20 m) vertical scales) regions of weakly stratified water with T-S characteristics similar to those within the northern-side mixed layer (Figure 3). These subsurface features were typically found between the 27.0 kgm^{-3} and 26.7 kgm^{-3} isopycnals (a layer that outcrops on the northern edge of the front) at distances as far as 50 km south of the frontal interface. The features nearest the front also exhibit elevated bio-optical signals similar to those found in the northern mixed layer, suggesting that the waters have been recently subducted beneath the southern mixed layer.



(a)



(b)

Figure 2. (a) Mixed layer depth and temperature through successive occupations of Section 2. Mixed layer depths were estimated using a 0.1 kgm^{-3} density change from surface values, and are thus a bulk measure of stratification rather than a strict estimate of mixed layer thickness. The mixed layer generally deepened and cooled with the passage of successive cold air outbreaks, though areas of shoaling and warming were also observed. Mixed layers were shallow near the front and deepest far to the north, in the 2 °C waters beyond the secondary front. The apparent sharpening of the subpolar front is largely an artifact of section orientation. (b) Comparisons between depth integrated (surface to 27 kgm^{-3} isopycnal) change in heat content and estimated net surface heat loss along Section 2. Blue lines indicate change in integrated heat content between successive occupations while red lines mark the time integrated net surface heat flux derived from shipboard meteorological measurements. Although surface cooling and mixing are clearly important, it is no surprise that observed changes in integrated heat content indicate that advection plays an important role in governing upper ocean evolution near the front.

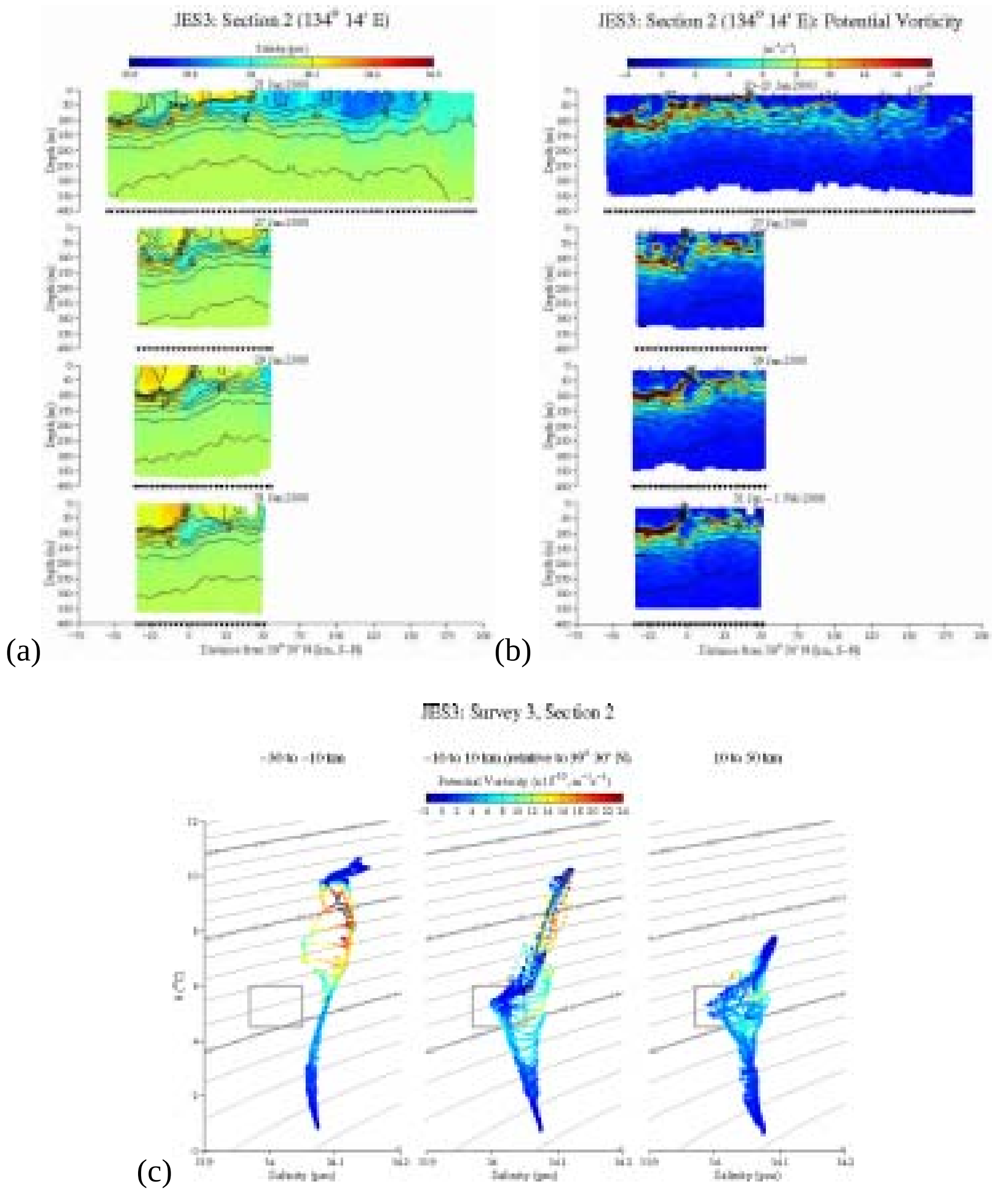


Figure 3. (a) σ_θ-/salinity (contours/colors) and (b) σ_θ-/2-D potential vorticity (neglecting along-front velocity and density gradients) from the four occupations of Section 2. Patches of anomalously fresh, weakly stratified water sit within the otherwise strongly stratified region below the mixed layer base. Small patches appear south of the subpolar front, with thicker patches near the interface. These regions have low potential vorticity and watermass properties similar to those found in north-side mixed layers, consistent with the hypothesis that these parcels originated in the northern surface layer and have since moved southward and downward (and likely eastward, in the along-front flow) along isopycnals. (c) Temperature-salinity-potential vorticity (colors) diagrams for a single occupation of Section 2. The left panel displays profiles taken far south of the subpolar front, the middle panel shows profiles taken near the front and the right panel presents profiles taken far to the north. Background contours mark isopycnals and a gray box highlights water properties associated with the mixed layer north of the subpolar front. The north-side mixed layer (right) exhibits low potential vorticity, salinities < 34 psu and temperatures < 6 °C. Water parcels with similar characteristics appear beneath the surface layer in the vicinity of the front (center), but are absent far to the south (left).

RELATED PROJECTS

Our efforts are part of an intensive, multi-investigator study of the Japan/East Sea. We anticipate cooperation with the following components:

Satellite Characterization of Bio-Optical and Thermal Variability in the Japan/East Sea, B. Arnone, (NRL).

Atmospheric Forcing and its Spatial Variability over the Japan/East Sea, R. Beardsley, A. Rogerson (WHOI) and C. Dorman (SIO).

Optical Properties as Tracers of Water Mass Structure and Circulation, G. Mitchell, D. Stramski and P. Flatau (SIO).

Modeling Support for CREAMS II: Oceanic and Atmospheric Mesoscale Circulation and Marine Ecosystem Simulations for the Japan/East Sea, C. Mooers and S. Chen (University of Miami).

Wind Forcing of Currents in the Japan/East Sea, P. Niiler (S.I.O.), D. Lee (Pusan National University) and S. Hahn (National Fisheries Research and Development Institute).

Observations of Upper Ocean Hydrography and Currents in the Japan/East Sea using PALACE Floats, S. Riser (University of Washington).

Hydrographic Measurements in Support of Japan/East Sea Circulation, L. Talley (SIO).

Shallow and Deep Current Variability in the Southwestern Japan/East Sea, R. Watts and M. Wimbush (University of Rhode Island).

IMPACT/APPLICATION

Highly resolved, three-dimensional upper ocean measurements provide a unique picture of the integrated effects of wintertime water mass formation in response to strong atmospheric forcing. Simultaneous measurements of bio-optical properties contrasts conditions on either side of the front and permit us to study the role of dynamics in controlling bio-optical variability. Both at the subpolar front and off the Korean coast, SeaSoar surveys provide bio-optical measurements of unprecedented synopticity and horizontal resolution.

TRANSITIONS

None.

PUBLICATIONS

Fox, D.N., W.J. Teague, C.N. Baron, M.R. Carnes, and C.M. Lee, The Modular Ocean Data Assimilation System (MODAS), *Journal of Atmospheric and Oceanic Technology*, in press, 2001.

Gordon, A.L., C.F. Giulivi, C.M. Lee, A. Bower, H.H. Furey, and L. Talley, Japan/East Sea Intra-thermocline Eddies, *Journal of Physical Oceanography*, in press, 2001.

Lee, C. M., C. E. Dorman, R. W. Gould and B. H. Jones (1999) Perliminary Cruise Report: Hahnaro 5-Dynamics, Biology, Optics and Meteorology of the Subpolar Front in the Japan/East Sea. Technical Memorandum, APL-UW TM 3-99, Applied Physics Laboratory, University of Washington, 65pp.